MODELS AM-1, AM-2 & 190 LOW NOISE TRANSFORMERS

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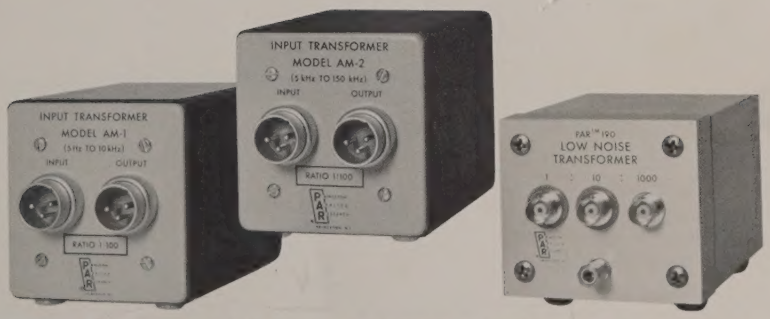

OPERATING AND SERVICE MANUAL

EG&G
PRINCETON APPLIED RESEARCH

MODELS AM-1, AM-2 & 190 LOW NOISE TRANSFORMERS

OPERATING AND SERVICE MANUAL

EG&G PRINCETON APPLIED RESEARCH

MDL AM-1, AM-2 & 190; 10/78-GG

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(2) Your name (instrument user).

(3) Your address.

(4) Address to which instrument should be returned.

(5) Your telephone number and extension.

(6) Symptoms (in detail, including control settings).

(7) Your purchase order number for repair charges (does not apply to repairs in warranty).

(8) Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).

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TABLE OF CONTENTS

Section		Page
I	SPECIFICATIONS	I-1
II	NOISE AND SOURCE RESISTANCE	II-1
III	DEGAUSSING PROCEDURE	III-1
IV	DIAGRAMS AND PHOTOGRAPHS	IV-1

SECTION I
SPECIFICATIONS

Three models of low-noise transformers are available: the AM-1, AM-2, and 190. They are especially useful for matching low-impedance sources to the high impedances typical of preamplifier inputs, and thereby improve low-noise performance.

A general-purpose frequency response and changeable turns ratio render the Model AM-1 the most versatile of the three transformers. The Model AM-2 is best for high frequency applications. The Model 190 is a low noise transformer having a frequency response extending downward into the millihertz region. See Section IV for wiring diagrams, photos, amplitude transfer curves, and noise figure contours for the three transformers. Instructions on how to use the noise figure contours are given in part II.

The AM-1 and the AM-2 each weigh 1 lb, and have dimensions of 3-1/16" W x 3-1/16" H x 4-1/4"D. The Model 190 weighs 5 lbs and is 3" W x 2.937" H x 5.812" D. All are free-standing.

As determined from the noise figure contours for the Model AM-1, for a turns ratio of 1:100 the optimum source resistance is between 10 and 100 ohms. If a source resistance in another range is to be used, the operator may consider changing the turns ratio to shift the low-noise resistance range to that being used. The source resistance scales of the noise figure contours and frequency response curves should be multiplied by a factor of $10^4/N^2$, where N is the step-up turns ratio being used. Required wiring and scaling information is given in the wiring diagram for the AM-1.

The AM-2 has a fixed 1:100 turns ratio.

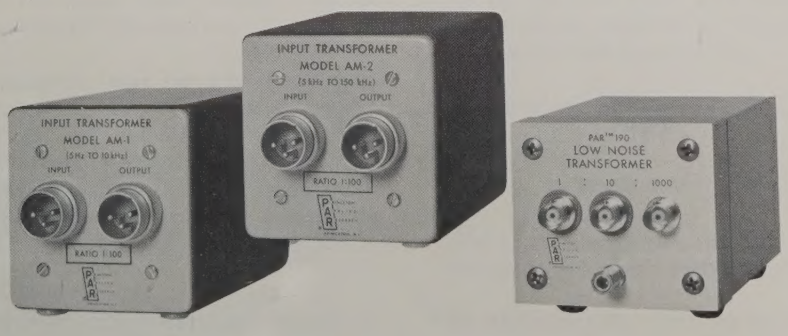
The Model 190 has two primary windings: P1, with a P1:S3 turns ratio of 1:1000, and P2, with a P2:S3 turns ratio of 1:100. Only one of these primaries should be connected at a time, with the unused winding left open.

An output cable, made up with connectors, is provided with each transformer manufactured. When ordering a transformer remember to specify which instrument it is to be used with so that the proper connector can be provided at the amplifier end of the cable. An input connector is provided with each AM-1 and AM-2. The cable connectors for the AM-1 and AM-2 are Cannon brand audio connectors type XLR-3-11C or XL-3-11C, or equivalent. The Model 190 uses standard BNC connectors. Cables should be short, to keep capacitance low, and of the low noise variety (such as Amphenol brand RG/U type 21-537 or 21-541).

On the Model 190, the outer shells of the input BNC connectors are floating off case ground. On the Models AM-1 and AM-2, the case ground is run to a separate input pin and not to either of the transformer input pins. (See wiring diagrams.) To maintain the common-mode rejection properties of these transformers, do not connect the input-cable shield to the transformer case ground. The shield *should* be grounded at the source end of the cable, however.

CAUTION: Be very careful to avoid applying a signal to the primary that will cause insulation breakdown of the secondary or damage to the input circuit of the preamplifier. This applies primarily to the Models AM-1 and AM-2; the Model 190 has a neon lamp across its secondary that prevents the secondary voltage from becoming greater than 100 V.

CAUTION: Avoid passing excessive dc current through the primaries of these transformers. More than 200 μA will permanently magnetize the core. A magnetized transformer is usually noisy and microphonic. See Section III for a degaussing procedure. *Do not measure winding resistance with an ohmmeter;* ohmmeter current is sufficient to magnetize the core. This caution applies primarily to the Models AM-1 and 190; because the AM-2 has a ferrite core, permanent magnetization will not occur as a result of dc current. However, excessive dc current in the primary, along with the signal might result in premature saturation of the core and distortion of the signal.



SECTION II
NOISE AND SOURCE RESISTANCE

Best amplifier or transformer performance is often regarded to be realized under those conditions where it least decreases the overall signal-to-noise ratio. In many instances, the thermal noise generated by the signal source resistance is the dominant factor in determining the input signal-to-noise ratio (see Princeton Applied Research Corporation literature for discussions of other kinds of noise). In this respect, noise performance can be specified by the amount of noise the amplifier or transformer adds to the amplified or transformed source thermal noise; expressed in decibels this is called the "Noise Figure":

(1) Noise Figure =

$$20 \log_{10} \frac{\text{total rms noise voltage at the output}}{\text{gain x source thermal noise voltage (rms)}} \text{ dB}$$

where the source thermal noise = $\sqrt{4KTR\Delta f}$ volts rms = E, and

K = Boltzmann's constant, 1.38×10^{-23} joules/K
T = absolute temperature in kelvins
Δf = equivalent noise bandwidth in Hz
R = source resistance in ohms

The total output noise may be converted to an equivalent input noise by dividing by the amplifier or transformer gain. The noise figure, expressed in these terms, becomes:

(2) Noise Figure =

$$20 \log_{10} \frac{\text{total rms voltage referred to the input}}{\text{source thermal noise voltage (rms)}} \text{ dB}$$

Each amplifier or transformer has its own characteristic set of noise figures, which vary as a function of frequency and source resistance. These figures are obtained experimentally and plotted graphically. Noise figure contours typical of preamplifiers are similar to those of transformers, the main difference being the preamplifiers generally have a higher range of resistance for which minimum noise figures occur.

Using the applicable set of contours, the total equivalent rms input noise can be determined:

(3) Total equivalent rms input noise voltage = source thermal noise x antilog NF/20 volts rms.

Notice from these equations that the equivalent noise bandwidth must be specified, usually determined by the external circuitry and/or the amplifier or transformer bandwidth. Only the overall or system bandwidth is of interest. Also, the operator must be careful to distinguish between equivalent noise bandwidth and other means of specifying bandwidth.

"Equivalent noise bandwidth" is a concept applying only to wideband noise. The concept arises from the fact that noise bandwidth is an unattenuated bandwidth, while signal bandwidth is specified as the number of Hz between two points of given attenuation on the response characteristic. Consider a filter with a given signal bandwidth, and imagine some amount of wideband noise, measured in volts/$Hz^{1/2}$, is applied to it. At the output of the filter, one would measure some smaller quantity of rms noise voltage. The equivalent noise bandwidth of the filter is defined as the unattenuated bandwidth of an equivalent theoretical (but physically impossible) perfectly sharp-cornered filter that, with the same wideband input noise, yields the same rms output noise as the filter of interest.

Obtaining exact conversion factors to equivalent noise bandwidth is complicated and depends on the specific rolloff characteristics of the system. Most often, however, actual numbers or accurate numbers are not important, and an approximation or even just an understanding of the situation will do. If the bandwidth is relatively wide and if the rolloff is reasonably sharp, the signal and equivalent noise bandwidths are nearly the same.

How a signal input transformer can improve the signal-to-noise ratio of an amplifier is illustrated in the following example:

Suppose one intended to operate a Model 113 Low Noise Preamplifier in conjunction with an experiment that presents a source impedance of 50 ohms, and suppose it is known that the information required from the experiment is below 1 kHz. Since the source thermal noise contributing to the total noise is dependent on bandwidth, the amplifier bandwidth is minimized by setting the LF rolloff control on the Preamplifier to dc and the HF rolloff control to 3 kHz. Dc coupling is used. If we assume that the equivalent noise bandwidth is approximated sufficiently by the signal 3 dB bandwidth as set on the front panel controls, the source thermal noise in this case is:

$$E = \sqrt{4 \times 1.38 \times 10^{-23} \times 2.9 \times 10^{2} \times 50 \times 3 \times 10^{3}}$$

$$= 4.9 \times 10^{-8} \text{ V rms}$$

From the noise figure contours for the Model 113, on page IV-13, the noise figure at a center frequency of 1500 Hz and a source resistance of 50 ohms is 18 dB. Substituting these values into equation (3):

$$\text{total equivalent rms input noise} = 4.9 \times 10^{-8} \times 10^{18/20}$$

$$= .39 \ \mu\text{V rms}$$

The 18 dB noise figure increases the equivalent input noise voltage by a factor of eight (.39 μV ÷ .049 μV).

By using an input transformer, we can reduce the noise figure to near zero. This is possible because of the property

of a transformer to multiply the source resistance by the square of the turns ratio and the voltage by the turns ratio. From the Model 113 noise figures, to reduce the NF to within 0.05 dB the source resistance should be about 1 megohm. The transformer turns ratio for this impedance increase is $\sqrt{R_2/R_1} = 140$. The thermal source noise at the amplifier input is equal to the noise generated by the 50 ohm source multiplied by the turns ratio. (The Model 113 input resistance is very much larger than the 1 megohm presented by the transformer, so that transformed voltages are not shared with the transformer impedance.) With a noise figure near zero, the increase in the equivalent input noise is small, and the noise, to a close approximation, is simply the noise generated by the 50 ohm source multiplied by the turns ratio, = 6.9 μV. Although the numerical value of equivalent input noise is much larger than before, this is only due to the transformer gain. Remembering that the signal is also increased by the transformer gain, we can see that the signal-to-noise ratio is substantially improved and equals the maximum possible value: $e_{sig}/(E \times \text{antilog } NF/20) \cong e_{sig}/E$. Without the transformer, the amplifier added noise (18 dB) causes a factor of eight degradation in the signal-to-noise ratio. With the transformer, this degradation does not take place; both the signal and noise are increased by the same factor, but the additional noise introduced by the amplifier is reduced to a negligible level (.05 dB).

Note that the noise contributed by the transformer is not included in the preceding analysis, nor are the effects the transformer might have on bandwidth. In addition, it is seldom convenient to obtain a transformer having exactly the required turns ratio. We therefore have to use preamplifier transfer curves and noise figure contours measured with the transformer in the circuit in selecting a transformer that comes closest to having the above ideal characteristics, i.e., a turns ratio of 140 and a response extending from dc to approximately 3 kHz.

The Model AM-1 (pages IV-2 through IV-5) has an available turns ratio of 1:145, but the frequency response drops off considerably at low frequencies. The Model 190 (pages IV-8 through IV-10) has better low frequency response, but has a turns ratio of 1:100 and slightly less high frequency response. To compare the relative performance of the two transformers, first refer to the Model AM-1 noise figure contours on page IV-2. Because the Model AM-1 would be operated with a turns ratio of 1:145, the noise figure contours from Figure 1 (plotted for a 1:100 turns ratio) must be "corrected" to take the higher turns ratio into account. This is most easily done by multiplying the source resistance values by the ratio of the squares of the turns ratios. The appropriate correction factor then would be $100^2/145^2 \cong 0.5$, and each source resistance value in Figure 1 should be reduced to half the stated value. Applying the correction and reading the noise figure for a 50 Ω source and operating in a band of frequencies below 1 kHz (recall that the information is assumed to be below 1 kHz), one obtains between one and three dB as a reasonable value of noise figure. In the case of the Model 190, the ratio is fixed at 1:100. Figure 11 (page IV-9) shows that the Model 190 exhibits a reasonably uniform 1 dB noise figure over the same bandwidth and from the same source resistance. This, coupled with the superior low frequency response of the Model 190 transformer (some of the signal information is presumed to be at low frequencies), makes the Model 190 the logical transformer choice in this example.

Because the bandwidth of the Model 190 is 1 kHz (see Figure 10, page IV-8), instead of 3 kHz (Model 113 passband as determined by HF Rolloff Control setting as explained earlier), the rms source thermal noise voltage would be smaller, 2.8×10^{-8} V instead of 4.9×10^{-8} V. If the signal amplitude is not reduced, this noise bandwidth reduction itself increases the signal-to-noise ratio. However, it is unfair to attribute this increase to the transformer: completely independent of transformer considerations, the bandwidth could (and should) be reduced using filters so that only the band of frequencies containing the information is passed. In this particular case, the transformer, in addition to optimizing the source resistance, conveniently fills the filter requirement as well. In any case, the transformer causes a reduction in noise figure from 18 dB to 1 dB, and the amplifier, instead of causing an eightfold increase in the noise, adds only a 10% increase to it.

SECTION III
DEGAUSSING PROCEDURE

All transformer cores saturate in magnetization (= B) after a given winding current has been reached ($\propto$ H = no. turns x i = magnetizing force, where i = current through winding). The voltage induced in the secondary is proportional to dB/dt, so that the secondary voltage is distorted on that part of the curve where B is not a linear function of H. A permanently magnetized core saturates at a lower level of H, and thereby reduces the maximum signal current that can be transformed without distortion. Figure 14A on page IV-11 shows a B-H curve and waveforms that graphically illustrate this core saturation and corresponding distortion. Note that the B-H characteristic is actually a loop; curves #1 and #2 of Figure 14A are only representative *"center lines"* of the corresponding loops. Actually, the loops are usually "squarish ovals", with different degrees of squareness for different core materials. The shape of the loop has much to do with distortion, but this is not of interest in this discussion, only the general situation of the loops with respect to saturation.

A magnetized transformer is usually noisy and microphonic compared to when it is not magnetized. This noise is the most objectionable characteristic of a magnetized transformer because it affects low level signals. The distortion of high level signals described here is not usually an operating problem because the signal is seldom so large. But high level distortion is useful in determining the condition of the core and in monitoring the degaussing process.

Notice from Figure 14A that as long as the core is not magnetized the transformer works on a loop around center line #1 and the signal can be of maximum amplitude. If the core becomes permanently magnetized, the transformer works on a loop around center-line #2 (or equivalent for opposite polarity), and, if the same maximum signal current is applied, the core becomes saturated at one of the peaks of the signal. B, C, and D of Figure 14 show a primary signal current, corresponding core magnetization, and corresponding induced secondary voltage for a magnetized-core transformer with large signal input. Notice that the permanently magnetized core saturates sooner for one polarity of signal and later for the other polarity.

To demagnetize (degauss) the transformer, it is necessary to pass a relatively large ac current through the primary, then to very slowly decrease this current. The secondary should be open. The degaussing current is initially large enough to magnetize the core in the direction of each corresponding polarity excursion of this current, and overrides the initial magnetization. The object of decreasing the current slowly is so that each successive magnetization is slightly less than the preceding one of the opposite polarity. As the current is decreased, the core is progressively less magnetized until it is no longer magnetized at all. Figures 15A, B, and C on page IV-12 illustrate the secondary waveforms as the transformer becomes demagnetized. **IMPORTANT:** Use a LOW FREQUENCY degaussing current, 1 Hz or so, to avoid inducing excessively high voltage in the secondary, and monitor the secondary with a *high impedance* oscilloscope. The Model 190's secondary is protected by a neon lamp, but the Model AM-1 could suffer insulation breakdown if the operator is not careful.

NOTE

The following is provided to further clarify the figures that appear on pages IV-2 and IV-3. First of all, it should be pointed out that the noise figure contours illustrated in Figure 1 apply only with a turns ratio of 1:100. Note from Figure 1 that the source resistance which yields minimum noise figure is on the order of 30 ohms, the value given in Figure 3 as the optimum value to use when operating with a turns ratio of 1:100. If the transformer is operated with some other turns ratio, a different value of source resistance is required to achieve minimum noise figure. The source resistance for any given turns ratio can be computed by multiplying the optimum source resistance for a turns ratio of 1:100 by N^2/N_o^2 where N is 100 and N_o is the new turns ratio. For example, for a turns ratio of 1:50, the multiplying factor would be $100^2/50^2 = 4$, and the optimum source resistance would be 4 x 30 or 120 ohms. The optimum source resistance values given in Figure 3 were computed in this manner.

Note that the "desired primary impedance" values called out on the case of the AM-1 transformer are a factor of two lower than those given in Figure 3. Use of these lower values will result in significantly flatter frequency response at the expense of slightly degraded noise performance. As can be seen in Figure 2, frequency response is a sharp function of source resistance.

The contours illustrated in Figure 1 are based on measurements made with the AM-1 transformer operated in conjunction with a Type A Preamplifier. An altogether different set of contours will apply if the transformer is being operated with some other type of preamplifier. To determine the optimum transformer source resistance, the operator must first know the optimum source resistance of the preamplifier independent of transformer considerations. Practically speaking, in most experiments, one has some given and not easily alterable source resistance from which to work and the idea is to select the turns ratio which transforms that source resistance to the one which is optimum for the preamplifier in question. For example, suppose the source resistance of the experiment is 100 ohms and that the preamplifier achieves minimum noise figure with a source resistance of 10 megohms. Dividing 10 megohms by 100 ohms and taking the square root of the quotient, one obtains 1:316 as the desired turns ratio. The nearest available ratio provided by the AM-1 is 1:354, which would then be the ratio to use in the experiment.

As a final note, notice that the turns ratio given in Figure 3 apply with the secondary connected as indicated in the diagrams, that is, with the windings connected in series and with the "center tap" grounded. This connection is ideal for working into differential input preamplifiers. It is also possible to connect the two secondary windings in parallel, which allows an additional turns ratio of 1:25 (primary connected in 1:50 configuration) to be obtained. To make the changeover, one would break the connection between pins 6 and 7, and between the transformer pins and the output connector. Pin 5 would then be jumpered to pin 7 and pin 6 to pin 8. The 5-7 junction would be brought out to pin 1 of the connector to provide ground as before. The 6-8 junction would be brought out to pin 2 of the connector, and pin 3 would be unused. The disadvantage of this arrangement is that it allows the transformer to be used with single-ended input preamplifiers only.

SECTION IV
DIAGRAMS AND PHOTOGRAPHS

	Page
Table	IV-1
Noise Figure Contours for Typical Model AM-1 Transformer	IV-2
Frequency Response of Typical AM-1 Transformer	IV-2
Schematic of Model AM-1 Transformer	IV-3
Modifying the AM-1 Transformer for Connecting the Output to a Single-Ended Amplifier	IV-4
Photographs of Model AM-1 Transformer	IV-5
Frequency Response of Typical Model AM-2 Transformer	IV-6
Noise Figure Contours for Typical Model AM-2 Transformer	IV-6
Model AM-2 Schematic, Turns Ratio 1:100	IV-7
Photograph of Model AM-2	IV-7
Frequency Response of Typical Model 190 Transformer	IV-8
Noise Figure Contours for Typical Model 190-113 System	IV-9
Model 190 Schematic	IV-10
Photograph of Model 190 Transformer	IV-10
B-H Curve & Waveform	IV-11
Degaussing Waveforms	IV-12
Typical Noise Figure Contours for the Model 113 Low-Noise Preamplifier	IV-13

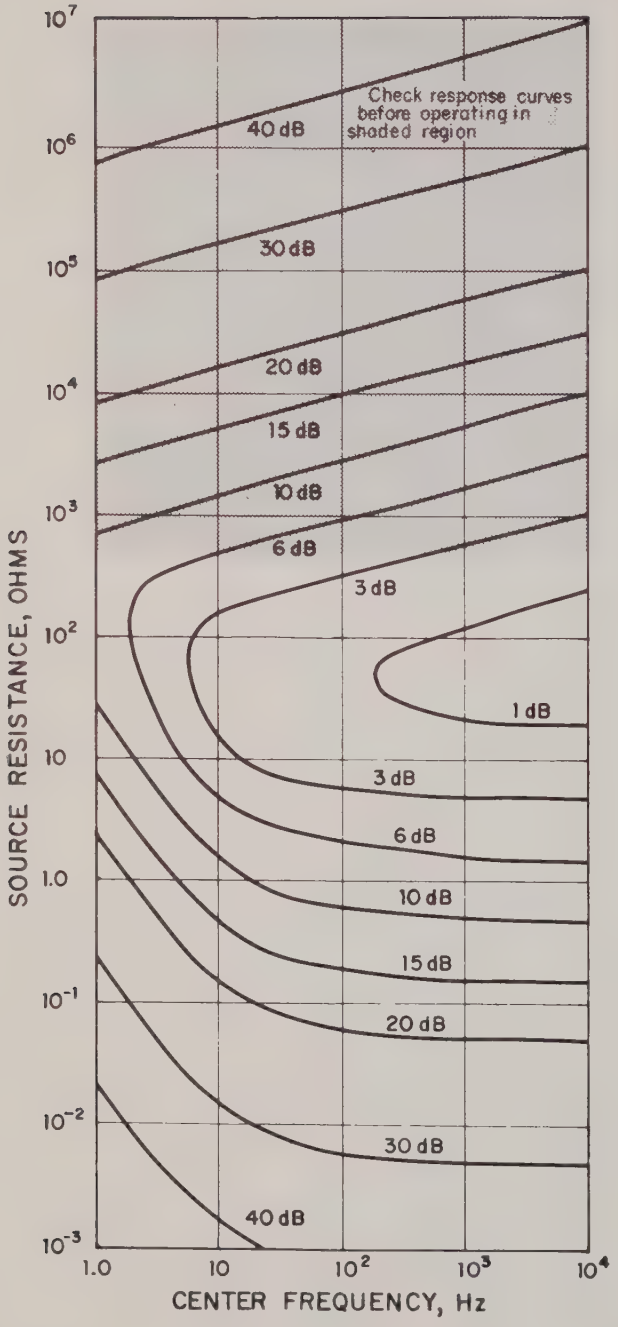


Figure 1. NOISE FIGURE CONTOURS FOR TYPICAL MODEL AM-1 TRANSFORMER

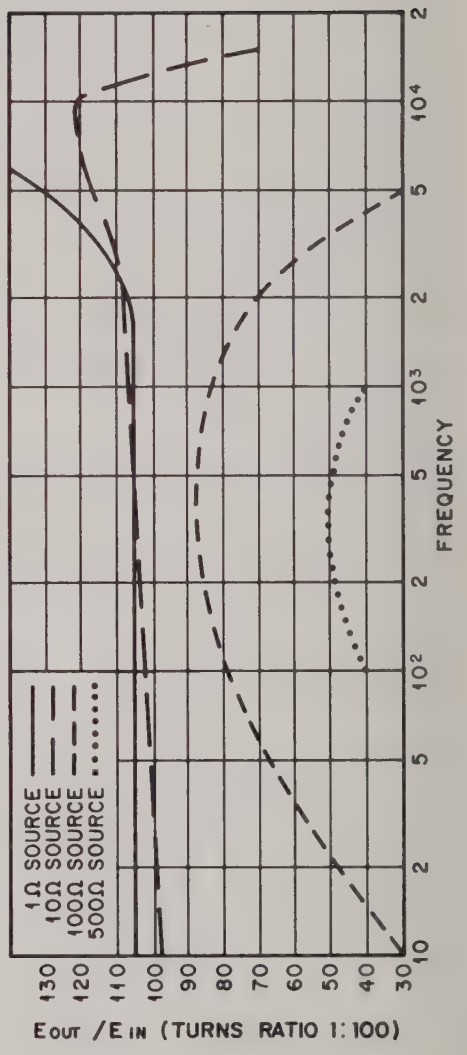
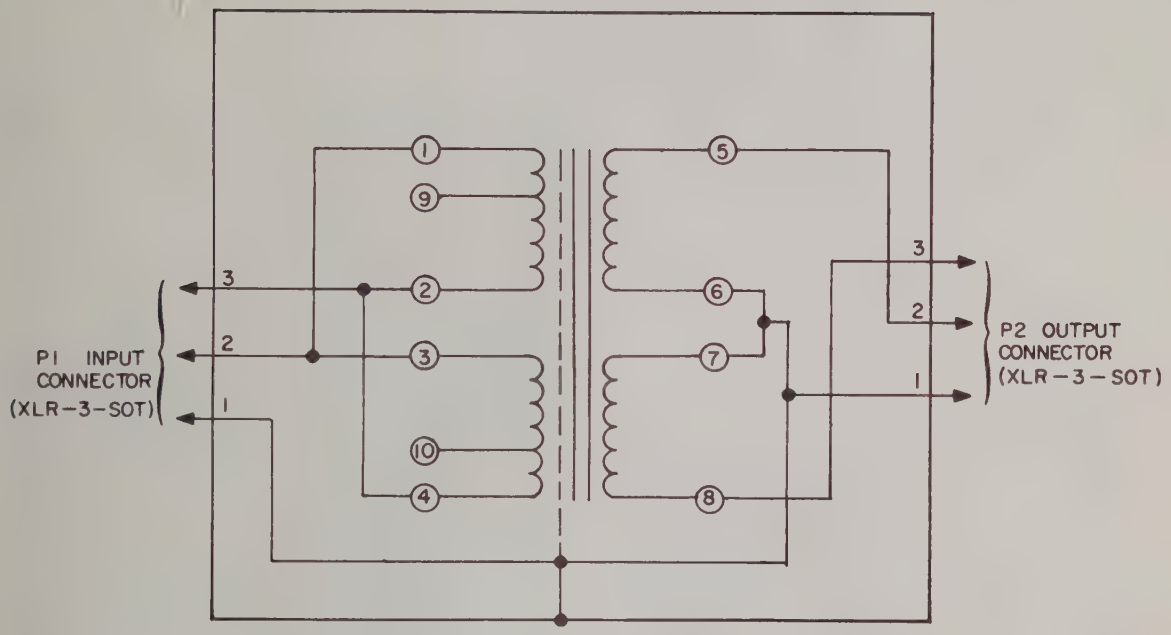


Figure 2. FREQUENCY RESPONSE OF TYPICAL AM-1 TRANSFORMER



Schematic of Model AM-1 Transformer, shown
for 1:100 turns ratio

The primary may be rewired for other turns ratios as follows:

Turns Ratio (1/N)	Optimum Source R	Connect Input To	Tie
51.1	120 ohms	1 & 4	2 – 3
59.7	80 ohms	1 & 10	2 – 3
72.3	60 ohms	9 & 10	2 – 3
79.3	50 ohms	1 & 4	9 – 3, 2 – 10
102	30 ohms	1 & 2	1 – 3. 2 – 4
145	13 ohms	9 & 2	9 – 3, 2 – 10
177	9 ohms	1 & 4	9 – 10
354	2.5 ohms	1 & 9	9 – 4, 1 – 10

Figure 3. SCHEMATIC OF MODEL AM-1 TRANSFORMER
(Secondary must be modified for application to single-ended amplifier)

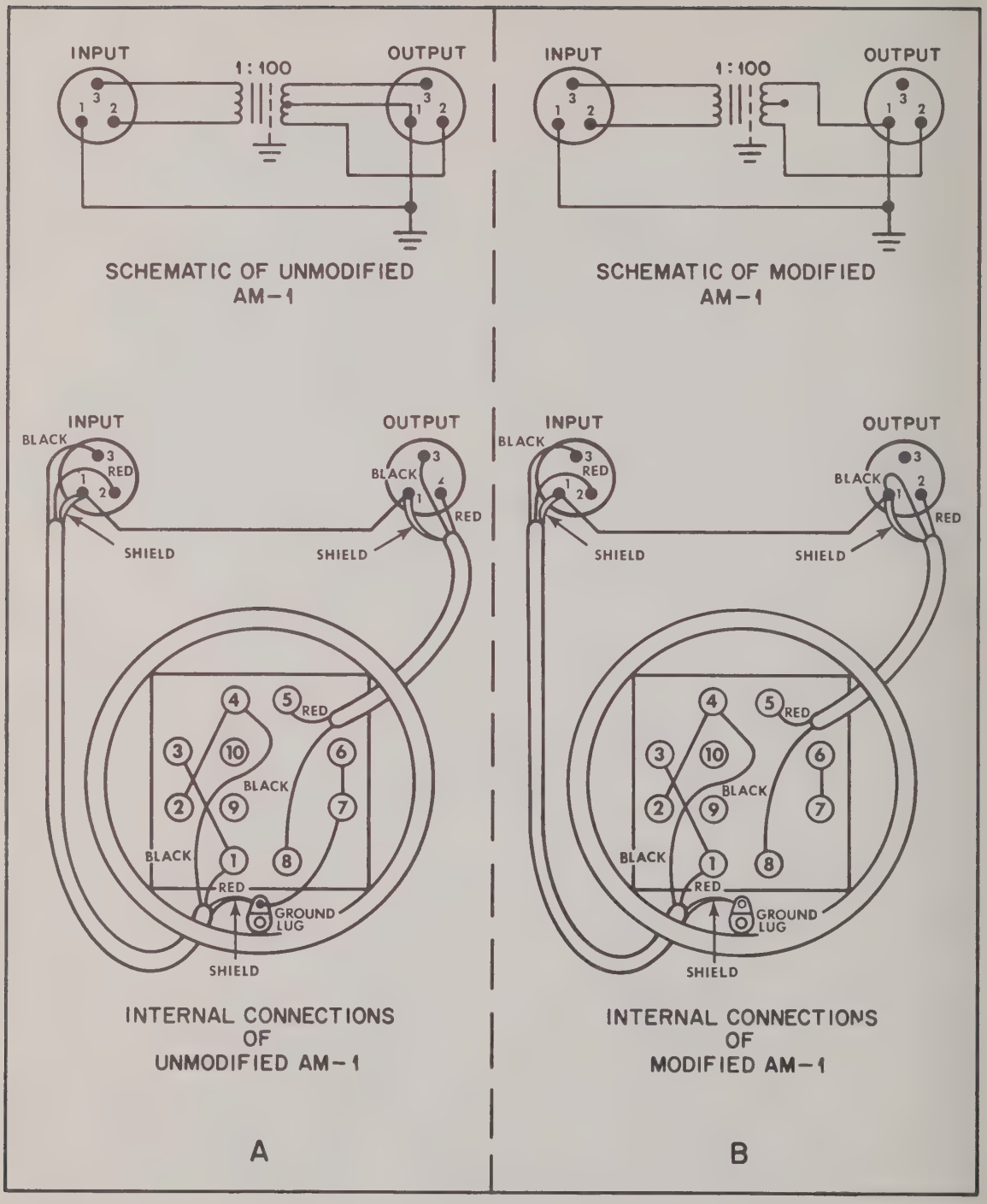


Figure 4. MODIFYING THE AM-1 TRANSFORMER FOR CONNECTING THE OUTPUT TO A SINGLE-ENDED AMPLIFIER

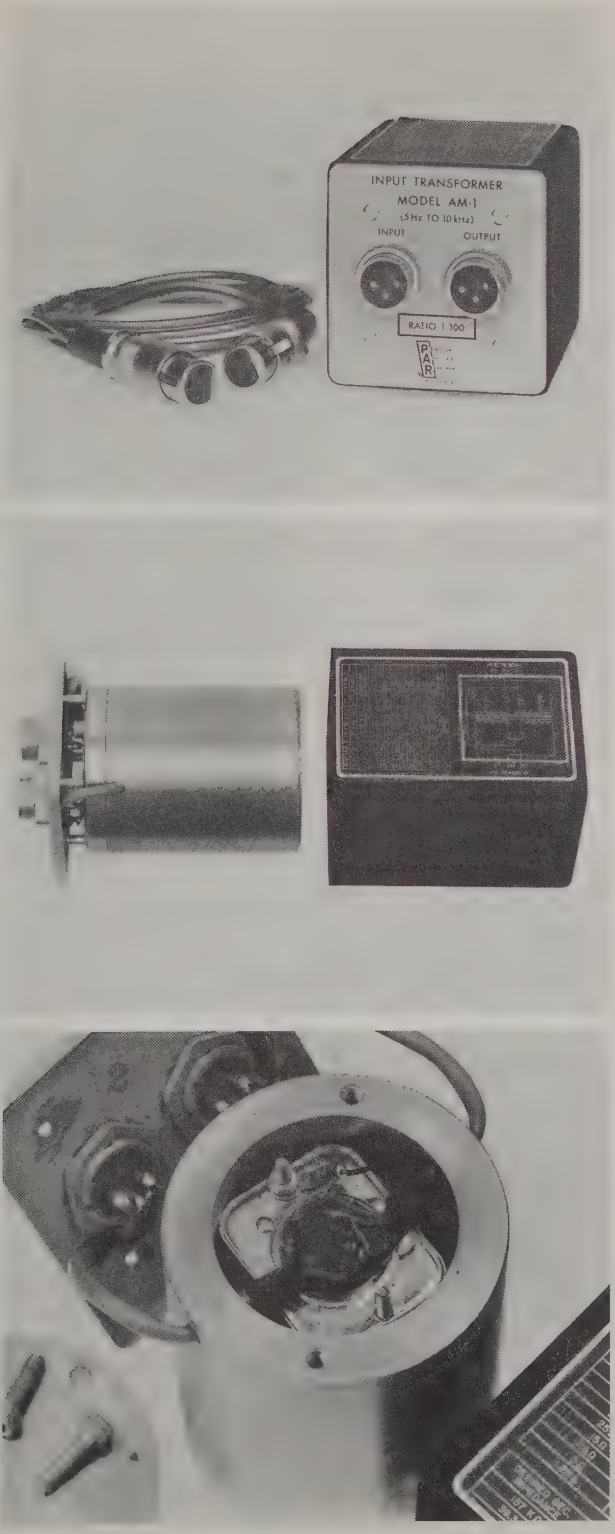


Figure 5. PHOTOGRAPHS OF MODEL AM-1 TRANSFORMER

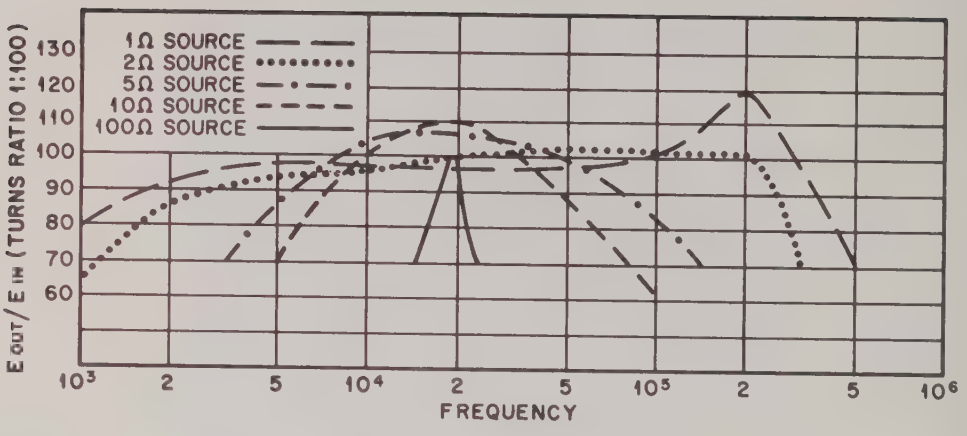


Figure 6. FREQUENCY RESPONSE OF TYPICAL MODEL AM-2 TRANSFORMER

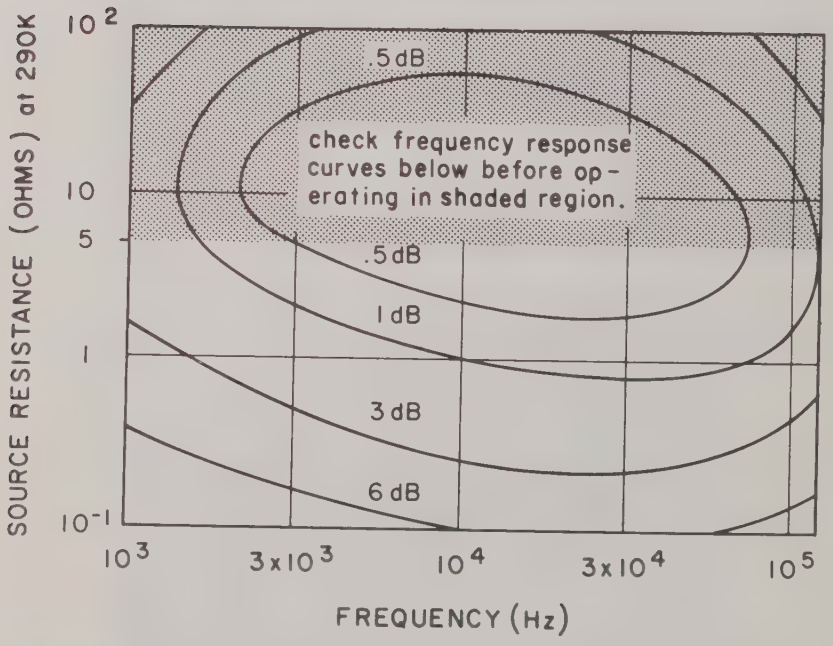


Figure 7. NOISE FIGURE CONTOURS FOR TYPICAL MODEL AM-2 TRANSFORMER

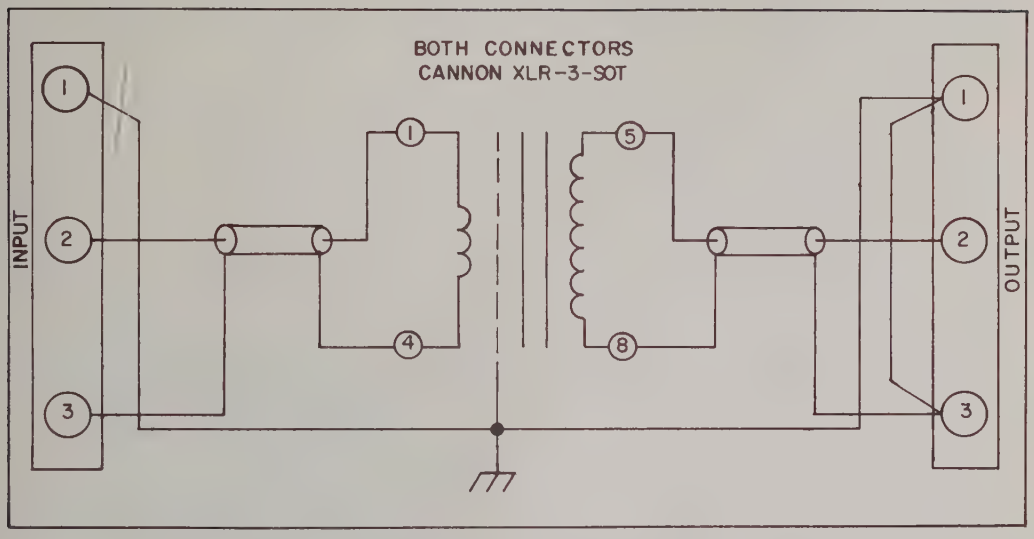


Figure 8. MODEL AM-2 SCHEMATIC, TURNS RATIO 1:100

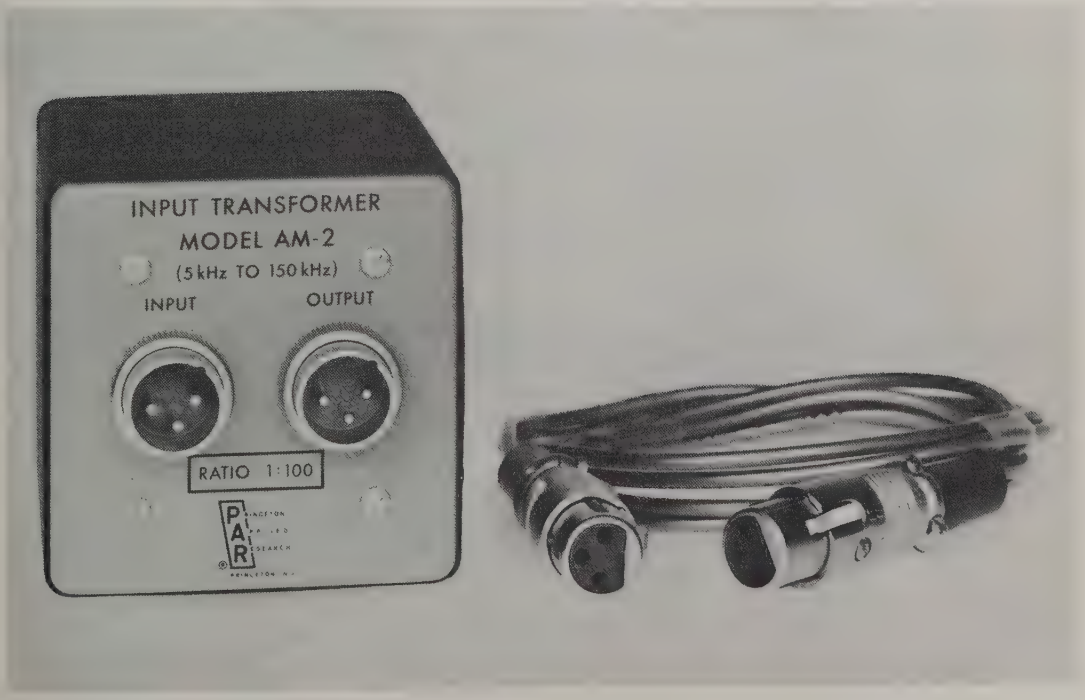


Figure 9. PHOTOGRAPH OF MODEL AM-2

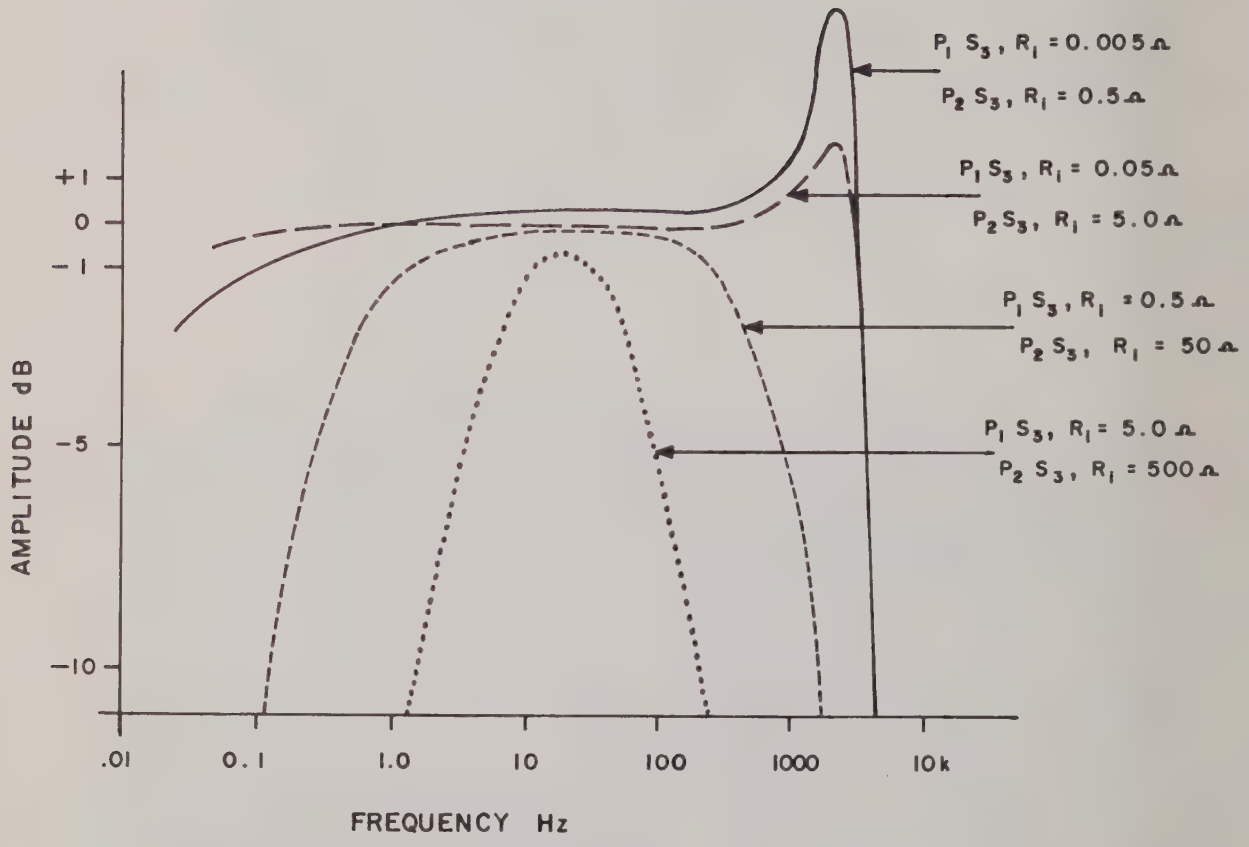


Figure 10. FREQUENCY RESPONSE OF TYPICAL MODEL 190 TRANSFORMER

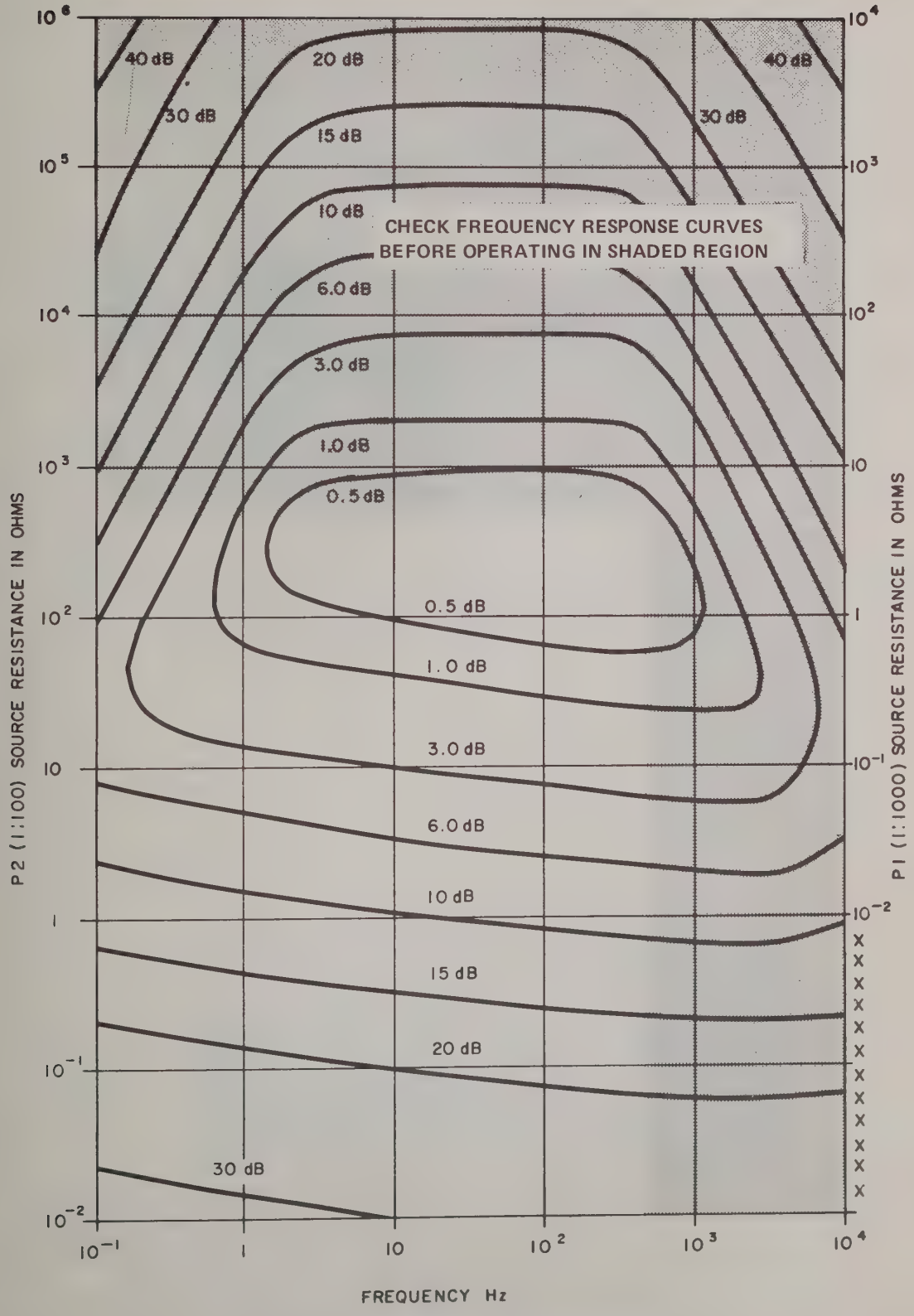


Figure 11. NOISE FIGURE CONTOURS FOR TYPICAL MODEL 190-113 SYSTEM

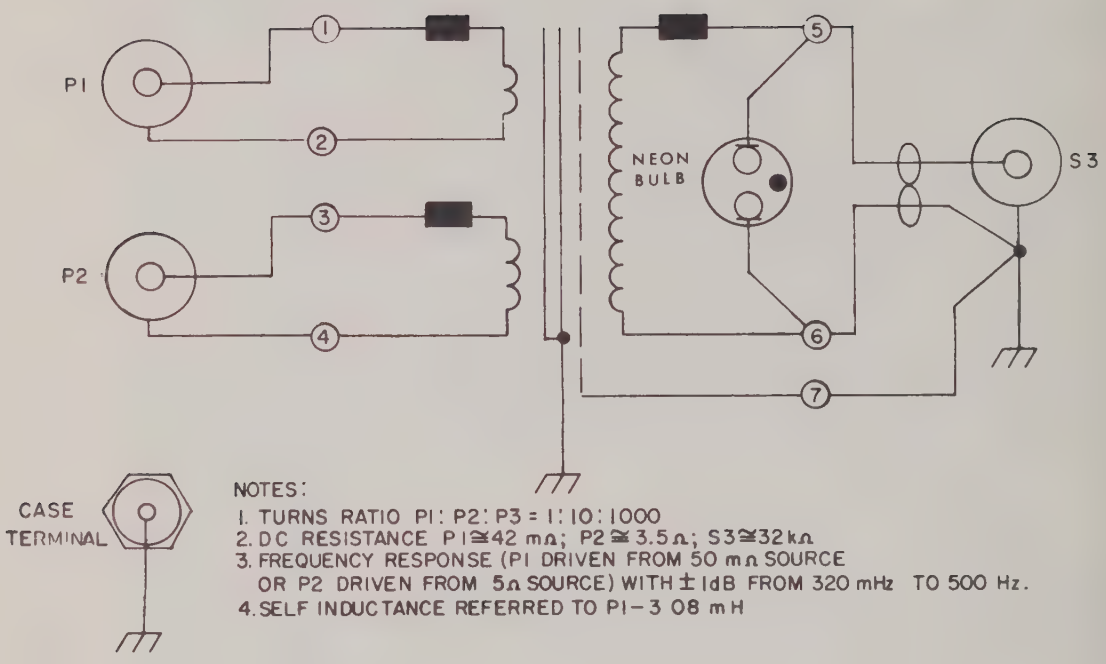

P1
P2
NEON BULB
S3
CASE TERMINAL
NOTES:
1. TURNS RATIO P1: P2: P3 = 1: 10: 1000
2. DC RESISTANCE P1≅42 mΩ; P2≅3.5Ω; S3≅32kΩ
3. FREQUENCY RESPONSE (P1 DRIVEN FROM 50 mΩ SOURCE OR P2 DRIVEN FROM 5Ω SOURCE) WITH ±1dB FROM 320 mHz TO 500 Hz.
4. SELF INDUCTANCE REFERRED TO P1-3 08 mH

Figure 12. MODEL 190 SCHEMATIC

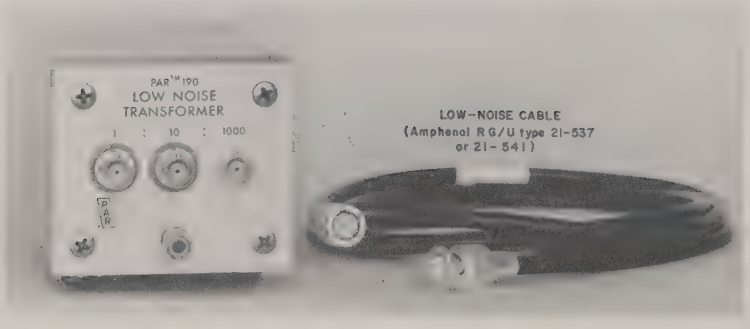


Figure 13. PHOTOGRAPH OF MODEL 190 TRANSFORMER

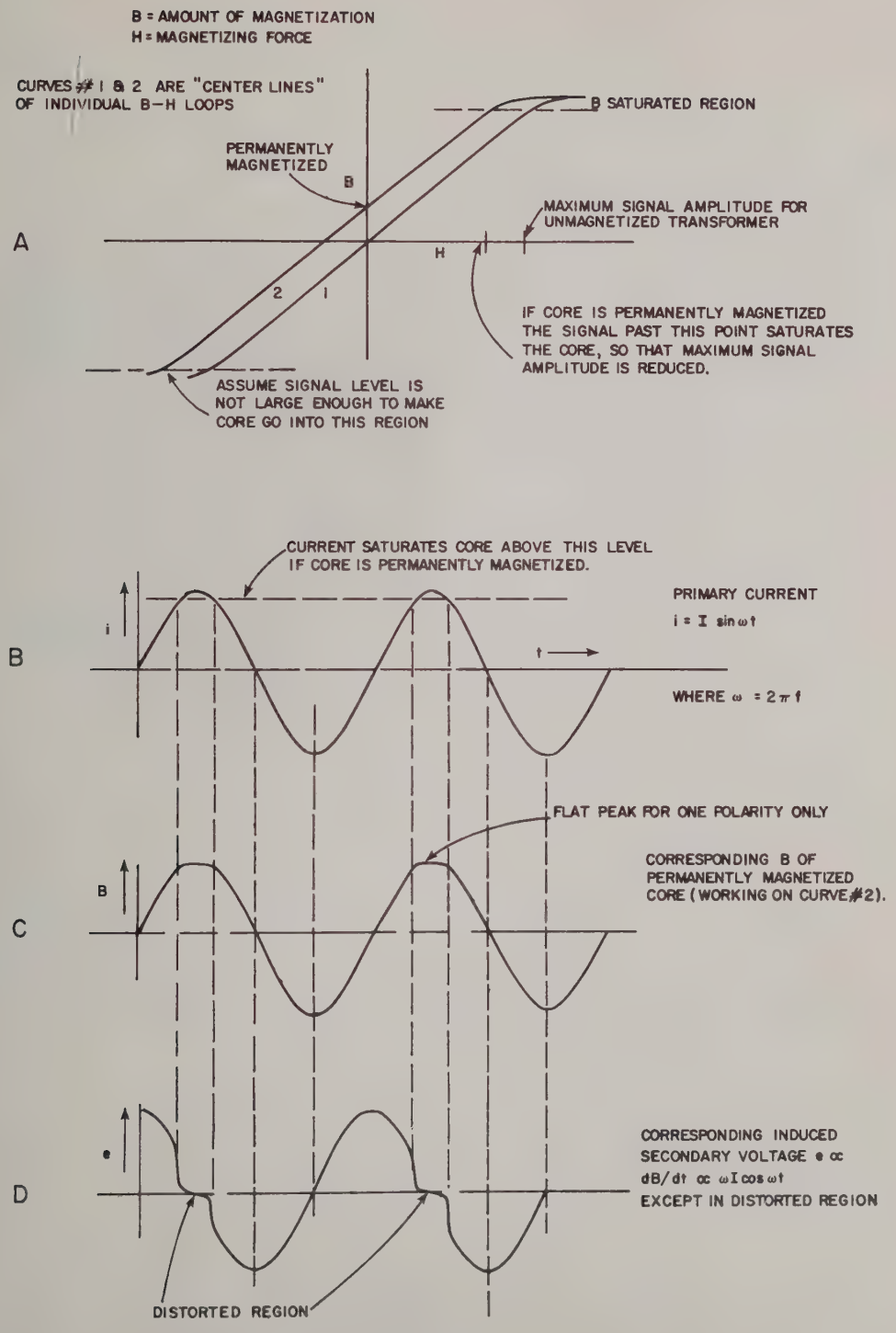

B = AMOUNT OF MAGNETIZATION
H = MAGNETIZING FORCE
CURVES # 1 & 2 ARE "CENTER LINES" OF INDIVIDUAL B–H LOOPS
B SATURATED REGION
PERMANENTLY MAGNETIZED
B
MAXIMUM SIGNAL AMPLITUDE FOR UNMAGNETIZED TRANSFORMER
A
H
2
1
IF CORE IS PERMANENTLY MAGNETIZED THE SIGNAL PAST THIS POINT SATURATES THE CORE, SO THAT MAXIMUM SIGNAL AMPLITUDE IS REDUCED.
ASSUME SIGNAL LEVEL IS NOT LARGE ENOUGH TO MAKE CORE GO INTO THIS REGION
CURRENT SATURATES CORE ABOVE THIS LEVEL IF CORE IS PERMANENTLY MAGNETIZED.
PRIMARY CURRENT
i = I sin ωt
i
B
t
WHERE ω = 2πf
FLAT PEAK FOR ONE POLARITY ONLY
CORRESPONDING B OF PERMANENTLY MAGNETIZED CORE (WORKING ON CURVE #2).
B
C
e
CORRESPONDING INDUCED SECONDARY VOLTAGE e ∝ dB/dt ∝ ωI cos ωt EXCEPT IN DISTORTED REGION
D
DISTORTED REGION

Figure 14. B-H CURVE & WAVEFORM

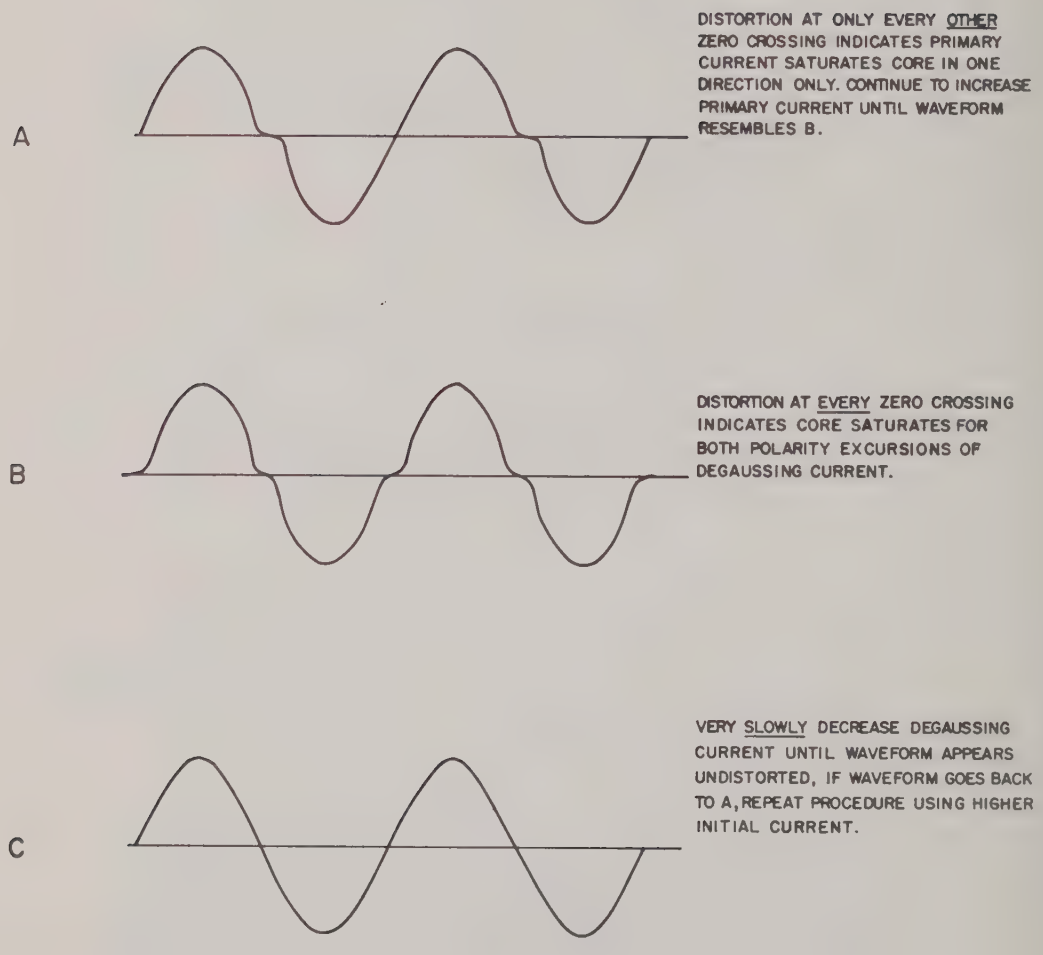

A
DISTORTION AT ONLY EVERY OTHER ZERO CROSSING INDICATES PRIMARY CURRENT SATURATES CORE IN ONE DIRECTION ONLY. CONTINUE TO INCREASE PRIMARY CURRENT UNTIL WAVEFORM RESEMBLES B.
B
DISTORTION AT EVERY ZERO CROSSING INDICATES CORE SATURATES FOR BOTH POLARITY EXCURSIONS OF DEGAUSSING CURRENT.
C
VERY SLOWLY DECREASE DEGAUSSING CURRENT UNTIL WAVEFORM APPEARS UNDISTORTED, IF WAVEFORM GOES BACK TO A, REPEAT PROCEDURE USING HIGHER INITIAL CURRENT.

Figure 15. DEGAUSSING WAVEFORMS

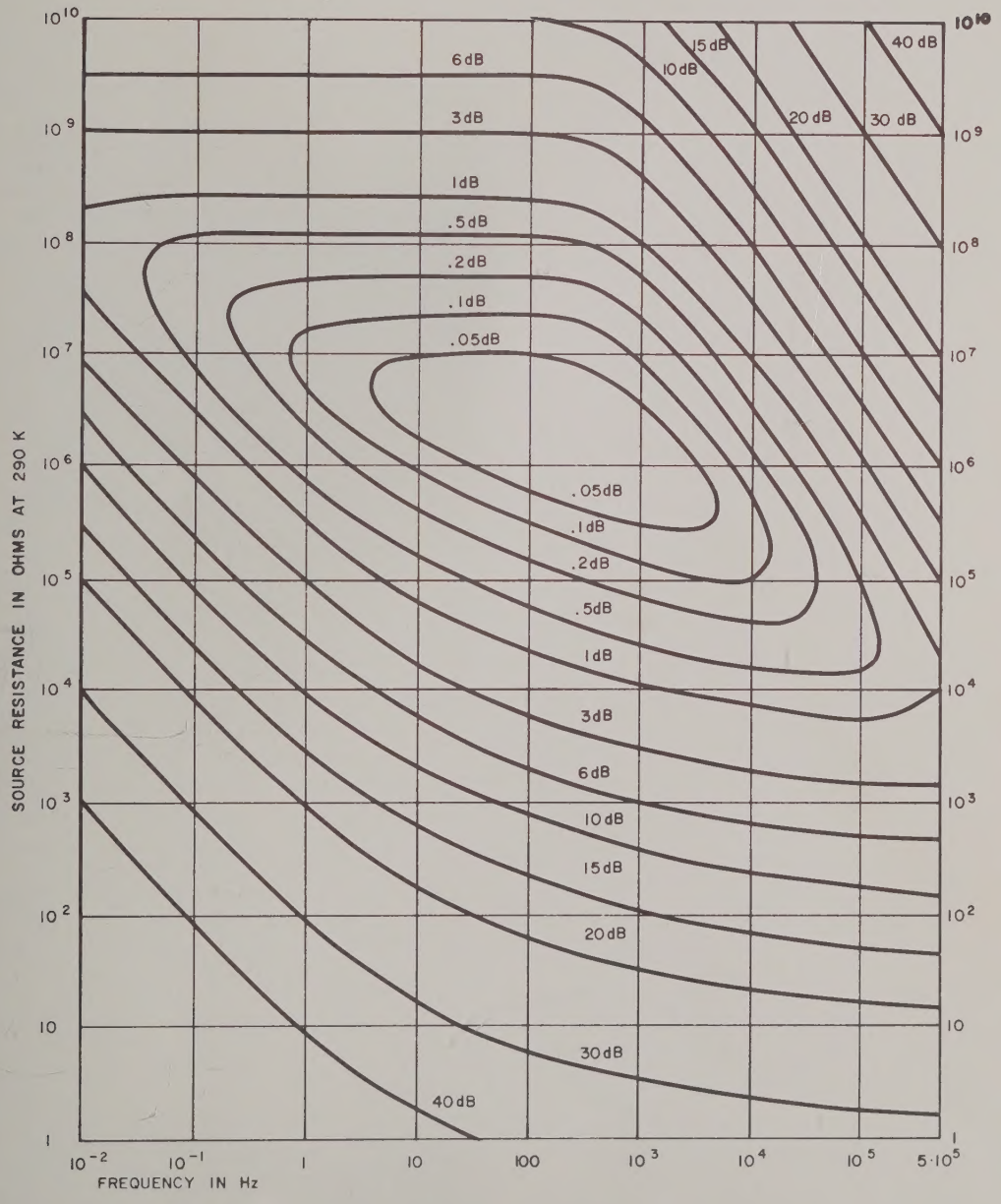


Figure 16. TYPICAL NOISE FIGURE CONTOURS FOR THE MODEL 113 LOW-NOISE PREAMPLIFIER

NOTE

MODELS AM-1, AM-2, & 190 LOW NOISE TRANSFORMERS
OPERATING AND SERVICE MANUAL

MP MASTER
MA29074

EG&G
PRINCETON APPLIED RESEARCH
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